KIET IJCE KIET International Journal of Communications &Electronics
Volume. No. 4, Issue No. 2, July-December 2016, ISSN: 2320 - 8996

Full-D2D Communications for Up-link/Down-link in Cellular Networks

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***Abstract*— Wireless communication services, cellular communication systems are small cells having small transmit powers. Device-to-device (D2D) communication is a promising idea to increase the performance of wireless networks. In D2D, users are communicating directly without going through base station. D2D communication is a new technology that allows mobile terminals to communicate directly with each other by the resources of cell sharing under the control of cellular systems. To improve utilization efficiency of the resource and increases the throughput of the system D2D communication is introduced into the cellular networks. D2D communication is classified into two bands, in-band and out-band. In this paper we investigate the applicability of in-band full-duplex (FD) radios in device-to-device (D2D) communication in cellular system. The full-duplex radios which can be used in D2D communication can double the spectral efficiency of the system. The existing radios which are not provide enough self-interference (SI) cancelation which are used in large transmit power systems. In this paper, we are considering the both up-link and down-link resources reuse of the cellular users by D2D communication. The results show that using FD radios in D2D system can double the throughput of the D2D link.**

***Keywords*— Device-to-Device (D2D) communications; full-duplex; up-link; down-link**

I. INTRODUCTION

Device-to-device (D2D) communication in cellular networks is the direct communication between two users without going through the Base Station (BS). The increasing demand for wireless communication having congestion of radio spectrum, which is an highly expansive. So, for better utilization of radio spectrum becomes important and are the new technologies required for this purpose. D2D communication nothing but the non-transparent to the cellular network and it can occur on unlicensed spectrum (i.e., outband) or cellular spectrum (i.e.,inband). In cellular network, all communications first go through the base station even if the both communicating parties or users in range for D2D communication. This process have the conventional low data rate mobile services such as text message and voice call in which users are not usually close enough to have direct communication. In today's mobile users, cellular networks use high data rate services e.g., gamming, video sharing in which they have potentially be in range for direct D2D communications. Therefore, a D2D user provides higher spectral efficiency and also causes mutual interference between cellular and D2D users.

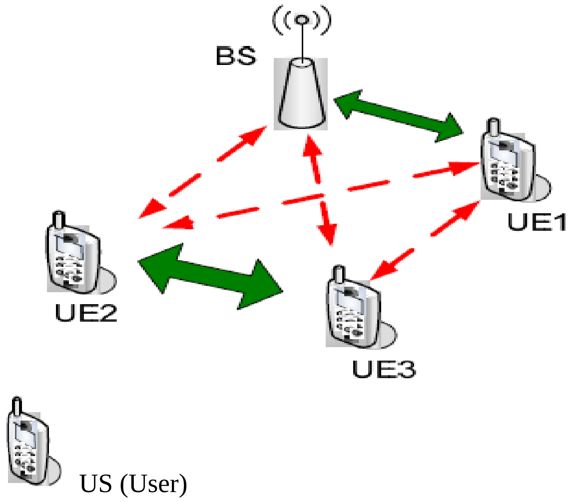

Fig. 1 Device-to-Device (D2D) Communications [1]

The advantages of D2D communications is not only limited to enhanced spectral efficiency but also in addition to improving spectral efficiency, D2D communications are potentially improve energy efficiency, throughput and delay [2]. Fig. 1 shows the general idea of D2D communication and UE1, UE2, UE3 are the users which are communicate with each other.

D2D is categorized into two bands, in-band and out-band shown in Fig. 2 [2]. Inband D2D which contains the majority of available work, to use the cellular spectrum for both D2D and cellular link. The importance for choosing inband communication is usually the highly control over cellular spectrum. The inband, D2D link uses licensed cellular bands. Inband can be divided into overlay and underlay categories [2]. In overlay, D2D links are use the dedicated cellular resources

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and in underlay cellular and D2D communication which can share the same radio resources.

In outband, D2D links are use unlicensed band. The importance of using outband D2D communication is eliminate the interference issue between D2D and cellular link. Other wireless technologies such as WiFi, ZigBee or Bluetooth are the unlicensed band. The connection is establishing in out-band D2D which can be done by users themselves which is called autonomous out-band or controlled outband means connection is establishing by the base station [2].

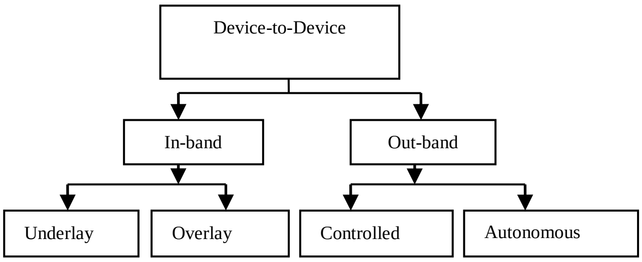

Fig. 2 Device-to-Device (D2D) Classification

Now days full-duplex radios designs have a lot of interest because of its potential to double the spectral efficiency of the system. In two way wireless communication systems, on the same frequency band one node cannot transmit and receive at the same time, the reason is that the one node will receive its own transmit signal, which is called as self-interference (SI) [2]. The self-interference can be up to millions of times stronger than the signal of interest, so it will impossible for self-interference to recover the desired signal. Solving this problem will lead to double the radio spectrum. This led to many full-duplex radio designs, the systems like antenna cancellation, two stage antenna cancellation, known as full-duplex MIMO, and most recently single antenna full-duplex radios and full-duplex MIMO are among attempts to builds full-duplex radios.

II. PROBLEM FORMULATION

Device-to-device communication is a new technology that can improve the system performance and has wide application areas like video delivery, relaying, machine-to-machine (M2M) communication, etc. Increased the number of users and systems that need wireless communications are congestion of radio spectrum in cellular system. Therefore effective use of spectrum has important and new technologies are required for this purpose. Full- duplex radio is design in this paper, because it has potential to double the spectrum efficiency of the system.

III. PROBLEM FORMULATION

Consider that D2D users are using the same radio resources in uplink transmissions in the cell. In this up-link transmission, the base station receives interference from D2D transmissions. D2D receivers will also receive interference from the uplink transmissions of the cellular users that are sharing the same resources as D2D link. In A_1 and A_2 are interference limited areas for D2D users D1 and D2, and radius of these areas are d_1 and d_2 respectively refer Fig. 3.

Throughput of the system of D2D link is increased. On other hand, while using full-duplex radios, throughput is affected by the residual of self-interference. Z_T is total throughput of the system when D2D link is activated

For half-duplex (HD) D2D:

$$Z_{T,HD} = Z_C + Z_{Cj,HD} + Z_{D,HD} \quad (1)$$

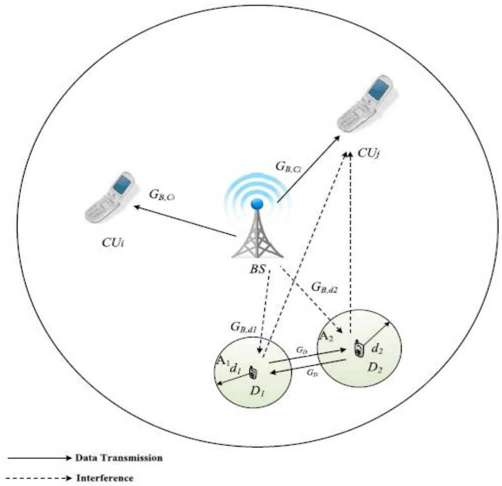

Fig. 3 D2D System Model [3]

For full-duplex (FD) D2D:

$$Z_{T,FD} = Z_C + Z_{Cj,FD} + Z_{D,FD} \quad (2)$$

In the above equation, Z_C is throughput of cellular users are not sharing resources with D2D users, $Z_{Cj,HD}$ and $Z_{Cj,FD}$ rate of cellular users that exploit the same resources as D2D users in half-duplex and full-duplex mode respectively. Rate of half-duplex D2D link is $Z_{D,HD}$ and for full-duplex D2D denote the rate by $Z_{D,FD}$. We consider γi to be the SNR of CUi at BS, $\gamma_{j,HD}$ and $\gamma_{j,FD}$ is the SINR of the cellular users which share the same resources as D2D users while D2D is in half-duplex and full-duplex mode. So the rates for cellular and D2D users are

$$Z_C = \sum_{i=1,i\neq j}^{M} \log_2(1+\gamma_i) \quad (3)$$

$$Z_{Cj,HD} = \sum_{j=1}^{M} \log_2(1+\gamma_{j,HD}) \quad (4)$$

$$Z_{Cj,FD} = \sum_{j=1}^{M} \log_2(1+\gamma_{j,FD}) \quad (5)$$

When D2D users operate in half-duplex mode, D2D user D_2 is transmitting and D2D user D_1 is receiving. Denote the SINR of D2D user D_1 as γ_{Dl}. Rate of the D2D link is

$$Z_{D,HD} = \log_2(1+\gamma_{Dl}) \quad (6)$$

When D2D users use full-duplex mode, both of D2D users transmit and receive at the same time and the throughput of FD D2D link rate is

$$Z_{D,FD} = \sum_{l=1}^{2} \log_2(1+\gamma_{Dl}) \quad (7)$$

For cellular transmissions, we consider P_{Ci} is the transmit power of CU_i and $G_{Ci,BS}$ is the gain of the channel between CU_i and BS. P_j is the transmit power of the cellular user which is using the same resources as D2D users and $G_{Cj,BS}$ is the channel gain between CU_j and BS, and $I_{Di,Cj}$ is the interference from D2D transmissions to cellular user CU_j.

SINR for half-duplex mode is

$$\gamma_{j.HD} = \frac{P_{Cj}.G_{Cj,BS}}{N_0 + I_{D2,Cj}} \quad (8)$$

SINR for full-duplex mode is

$$\gamma_{j.FD} = \frac{P_{Cj}.G_{Cj,BS}}{N_0 + I_{D1,Cj} + I_{D2,Cj}} \quad (9)$$

N_0 is additive white Gaussian noise in all the equation.

IV. FULL-DUPLEX D2D COMMUNICATION WITH DOWN-LINK RESOURCE

In this presents the downlink transmission resources are being shared with D2D users. In this case, D2D receivers will receive interference coming from base station. Cellular users, which share the same resources as D2D users, will also have interference because of D2D transmissions. Selecting the cellular users for resource sharing is important because of these interferences. Since cellular communications is the primary service, quality of service in cellular downlink transmissions needs to be guaranteed. For this purpose interference limited area method is used to select a group of users for resource sharing that would not face harmful interference from D2D transmissions. To minimize the interference on D2D link, we select the user with minimum transmit power from the group of users selected in ILA (Interference-limited-area) method. Fig. 3 shows the system model of D2D communication with downlink resource reuse. In the system model, A_1 and A_2 are the interference limited areas for D2D users D_1 and D_2 and d_1 and d_2 are the radius of these areas respectively refer Fig. 3. The rates in the system can be written as

$$Z_C = \sum_{i=1, i\neq j}^{M} \log_2(1+\gamma_i) \quad (10)$$

$$Z_{Cj,HD} = \sum_{j=1}^{M} \log_2(1+\gamma_{j,HD}) \quad (11)$$

$$Z_{Cj,FD} = \sum_{j=1}^{M} \log_2(1+\gamma_{j,FD}) \quad (12)$$

When D2D users operate in half-duplex mode, D2D user D_2 is transmitting and D2D user D_1 is receiving. SINR of D2D user D_l is denoted as γ_{Dl}. Rate of D2D link is

$$Z_{D,HD} = \log_2(1+\gamma_{Dl}) \quad (13)$$

When D2D users use FD, both of D2D users transmit and receive at the same time and D2D link rate is,

$$Z_{D,FD} = \sum_{l=1}^{2} \log_2(1+\gamma_{Dl}) \quad (14)$$

For cellular transmissions, we consider P_{Ci} is the transmit power of CU_i and $G_{BS,Ci}$ which is the channel gain between BS and CU_i. The transmit power of cellular user that is using the same resources as D2D users is denoted by P_j and $G_{BS,Cj}$ is the channel gain between base station BS and cellular user CU_j, and the interference from D2D transmissions to CU_i is denoted by $I_{Di,Cj}$. ICI is the Inter-cell interference. SINR for the cellular users in downlink without interference from D2D is

$$\gamma_i = \frac{P_{Ci}.G_{BS,Ci}}{N_0 + ICI} \quad (15)$$

SINR for cellular users with half-duplex D2D resource sharing is

$$\gamma_{j.HD} = \frac{P_{Cj}.G_{BS,Cj}}{N_0 + I_{D2,Cj} + ICI} \quad (16)$$

SINR for cellular users with full-duplex D2D resource sharing is

$$\gamma_{j.FD} = \frac{P_{Cj}.G_{BS.Cj}}{N_0 + I_{D1,Cj} + I_{D2,Cj} + ICI} \quad (17)$$

V. SIMULATION PARAMETERS

TABLE I

PARAMETERS

Parameter	Value
Cell Radios	500m
Maximum D2D Distance	25m
CUs Per Cell (N)	30
δ_{ILA}	0.01
δ_{B}	0.01
α	4
Maximum CU transmit power	23dBm
Noise Figure at CU	9dB
Noise Figure at BS	2dB

VI. SIMULATION RESULTS

A. For Up-link Resource Reuse

In this section we present the simulation results, for improve the performance of a D2D link in a particular cellular system. We consider, a single cell where 30 users are randomly dropped in the cell, maximum D2D distance is 25 meters.

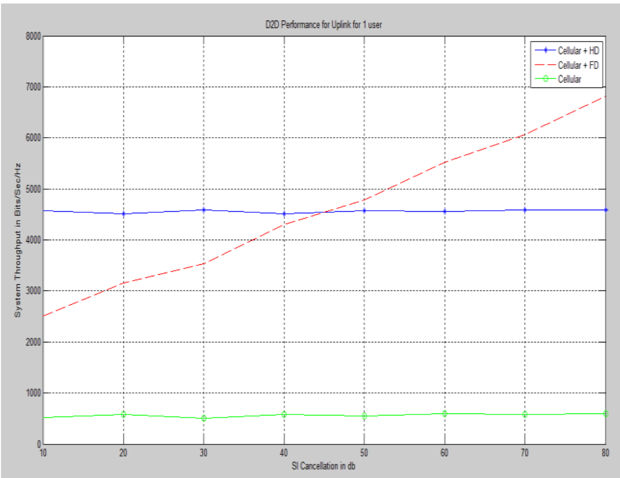

Fig.4 D2D Throughput Of System For One User Resource Sharing

Fig. 4 shows the throughput of the system when only one CU_j is the sharing resources with D2D and Fig. 5 shows K out of M users are sharing resources. Throughput of the system with full-duplex D2D will increase if the amount of self-interference cancelation increases, it is seen that for less 78 dB of self-interference cancelation half-duplex D2D has better performance due to large residual of self-interference.

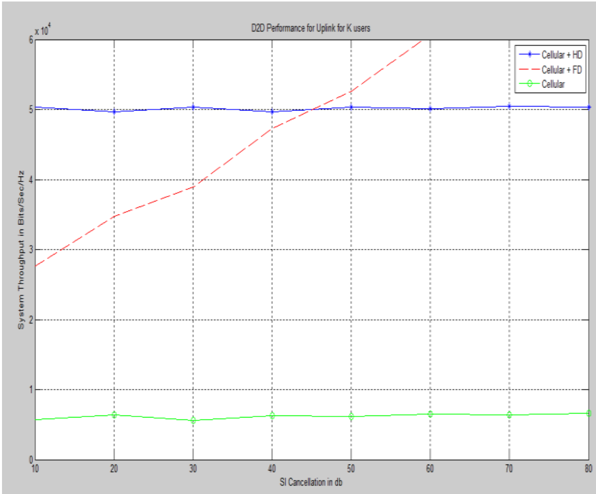

Fig. 5 D2D Throughput Of System For K Users Resource Sharing

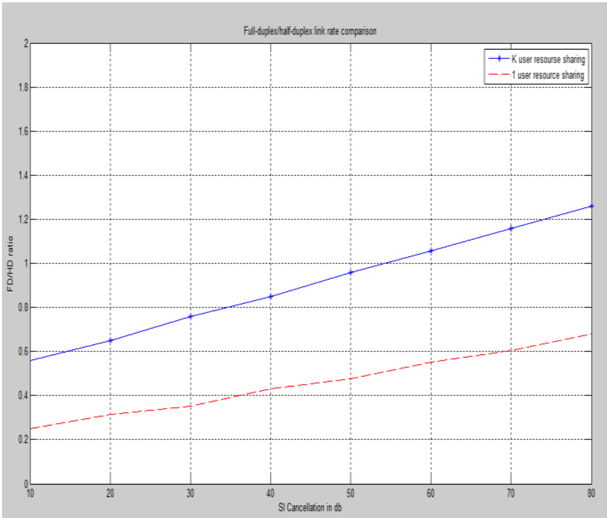

Fig. 6 Full-Duplex/Half-Duplex Link Rate Comparison.

Fig. 6 present the ratio of full-duplex D2D link rate over half-duplex D2D link rate for the two scenarios, when D2D sharing resources with only one cellular user is the first and second when resources of K users are being shared. In second case full-duplex outperforms half-duplex with lower amount of self-interference isolation.

Fig. 7 shows the full-duplex D2D over half-duplex D2D ratio versus SNR target for uplink signals for different self-interference cancelation amount. In this SNR increases, cellular users can transmit with larger power, this will result in larger transmit power for D2D users also.

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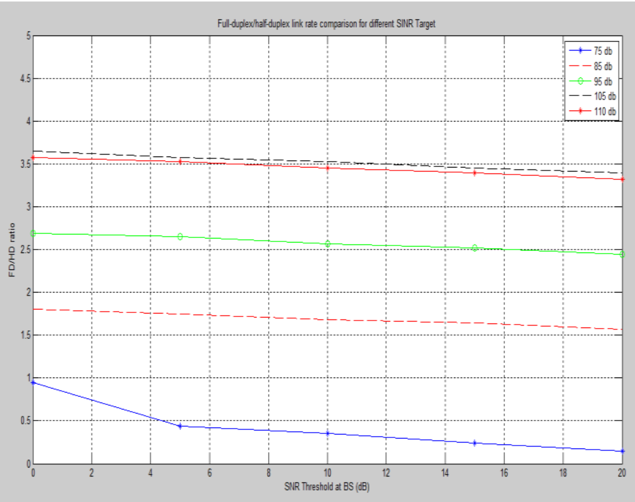

Fig. 7 Full-Duplex/Half-Duplex Link Rate Comparison For Different SINR Target.

B. For Down-link Resource Reuse

The simulation results for down-link resource reuse of cellular communications shows that how much of self-interference cancelation is required. Single cell results are presented first.

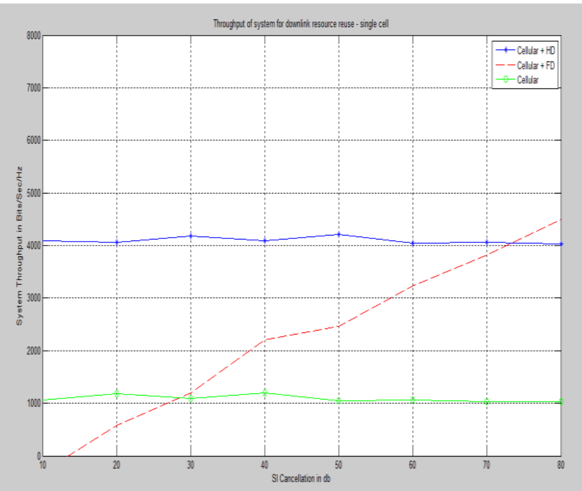

Fig.8 Throughput Of System For Down-Link Resource Reuse

Fig. 8 shows the throughput of the system in the presence of half-duplex D2D and full-duplex D2D based on different amount of self-interference cancelation. Throughput is constant for only cellular case and half-duplex D2D case. Full-duplex D2D rate increases as amount of self-interference cancelation increases. Half-duplex performs better than full-duplex when number self- interference cancelation is small and in full-duplex the self-interference is too large. While with around 100 dB self-interference suppression, theoretically full-duplex can almost achieve the doubling of throughput.

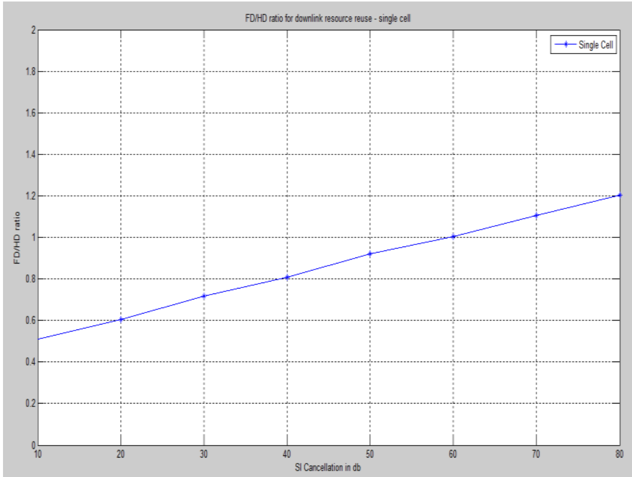

Fig. 9 FD/HD Ratio For Downlink Resource Reuse-Single Cell

Fig. 9 shows the ratio of full-duplex D2D link rate over half-duplex D2D link rate. This figure shows that full-duplex has double throughput compared the half-duplex, with is an ideal full-duplex scenario for D2D systems.

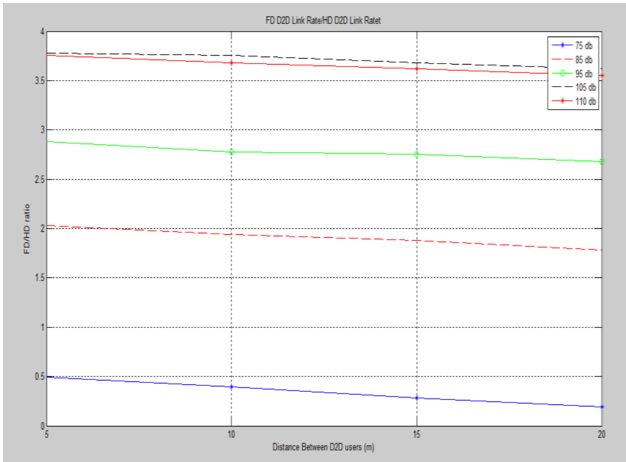

Fig.10 FD/HD Ratio Based On Distance

In Fig. 10, ratio of full-duplex throughput over half-duplex throughput is presented for 5 different amounts of self-interference cancelation, is based on the D2D users distance. The above figure shows that distance of the D2D users, has a huge effect on performance of full-duplex radios. Smaller distance leads to smaller transmit powers, which makes it easier to reduce the self-interference to noise floor, and have almost perfect full-duplex radios.

Fig. 11 shows, the throughput of the system for three modes, only cellular, half-duplex and full-duplex D2D. Similar to previous section, when the self-interference cancelation is small, then the full-duplex radios have worst performance.

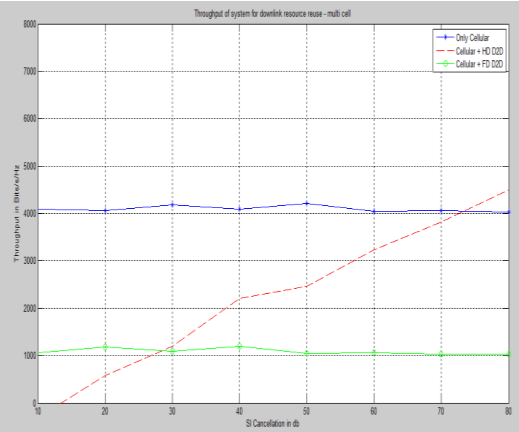

Fig. 11 Throughput Of System For Down-link Resource Reuse- Multi Cell

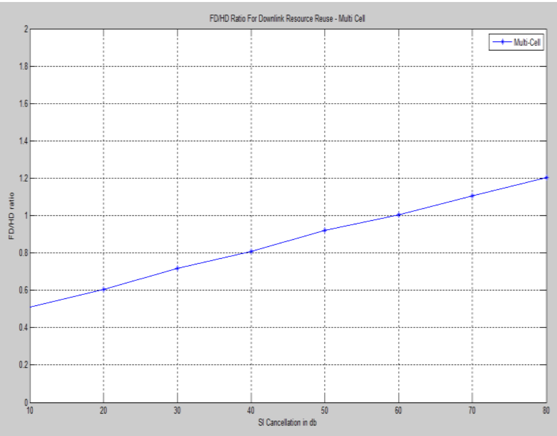

Fig. 12 FD/HD Ratio For Downlink Resource Reuse- Multi Cell

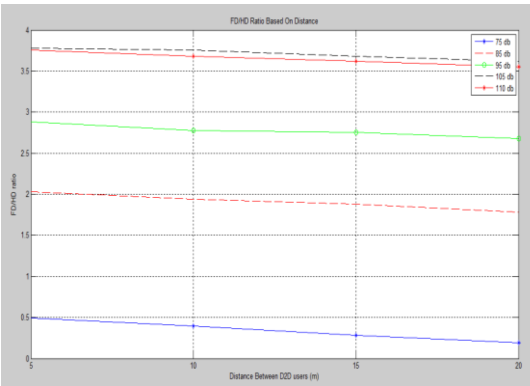

Fig.13 FD/HD Ratio Based On Distance

Frequency reuse factor in centre of the cell is one and in the edge of the cell frequency reuse of the three is used. This is called Partial Frequency Reuse (PFR) as shown in Fig.12.

In Figure 13, full-duplex over half-duplex rate ratio is depicted. Comparing this figure to figure 9 for single cell scenario, we see that in multi-cell case, full-duplex have better performance.

VII. CONCLUSIONS

In this paper, we investigated the both full-duplex D2D communication with uplink and downlink resource reuse. Uplink power control and interferences-limited-area method are presented for interference management. The simulations show the performance gain that can be obtained by using full-duplex radios in D2D and the amount of self-interference cancelation required for full-duplex radios so they can be used in D2D. Results show that available full-duplex systems can be considered as ideal for D2D communications, since D2D is for short distances with small transmit powers. And in downlink resource reuse, D2D users have self-interference cancelation systems and it can be operate in both half-duplex and full-duplex modes. Interference-limited-area is used for interference management on cellular users. Simulation shows that inter-cell interference effect the self-interference cancelation requirements for full-duplex radios since it increases the signal-plus-noise ratio in D2D receivers. Results show that full-duplex is possible for D2D communication and can be considered in future wireless systems. A D2D user provides higher spectral efficiency and also causes mutual interference between cellular and D2D users by using full-duplex technique.

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